Continuous power

Digital static transfer switches for increased data center reliability

CHRISTOPHER BELCASTRO, HANS PFITZER – The information flowing through data centers is, in many cases, essential to the smooth running of modern society. For this reason, it is vital that a data center is available at all times. The power grid cannot always be relied upon, and, consequently, every data center has a backup power scheme. When the grid power degrades or disappears this fact must be instantly recognized and the backup power must be brought in so quickly that the changeover is invisible to the data center. Static transfer switches provide an ideal way to do this and these sophisticated products have become an established component of all mission-critical data center architectures.

A transfer switch is an electrical device that switches a load between two power sources either manually or automatically. Thirty years ago, Cyberex, a member of the ABB Group, revolutionized power distribution with its invention of the digital static transfer switch (DSTS). Since then, Cyberex has installed more units than any other manufacturer. The ABB DSTS uses power semiconductors, specifically silicon-controlled rectifiers (SCRs), as high-speed, open-transition switching devices to deliver quality power to a customer's critical load. "Digital" refers to the technologies implemented – namely, digital signal processing (DSP) hardware and patented software that performs real-time analysis of the source waveforms and logic control of the DSTS.

Basic STS characteristics

ABB's two-source DSTSs are designed to power mission-critical loads where continuous conditioned power and zero downtime are required [1,2]. The DSTS is fed by two independent power sources ("preferred" and "alternate") that remain isolated from each another in all operating modes.

The power quality (PQ) on each source is continuously monitored in terms of its voltage, phase and waveform. If a source's PQ falls outside user-defined limits for a set period of time, the DSTS makes the decision to transfer to the other source. Typically, the switching time from the detection of an anomaly to completion of the transfer is one-quarter of a voltage cycle, or about four milliseconds. The switching technique employed is an open transition or "break before make" transfer. In this way, a data center load can be protected from even very short interruptions, or from any surges or sags in the primary power source.

The ABB DSTSs discussed in the subsequent sections are three-phase units operating between 100 and 4,000 A, at 208 to 600 V ➔ 1.

To make the device maintainable without causing downtime, the design of the ABB DSTS includes plug-in style molded case switches (MCSs) that provide isolation for regular maintenance and guided bypass. The MCS provides short-circuit interrupt capability, while eliminating nuisance tripping arising from the lack of an overload trip element. A traditional two-source DSTS incorporates six MCSs: two for source inputs (isolated), two for bypass (maintenance) and two parallel MCSs at the output to ensure no single point of failure through the switching elements and to electrically isolate the SCRs when maintenance is required ➔ 2.

Reliability

The features described above are not the only aspects that enhance ABB's DSTS reliability:

– Type II rated SCRs provide optimal fault clearing capability that coordinates with upstream protection.
– Redundant output switches prevent a single point of failure.
– Infrared ports allow thermal monitoring of critical load connections, without introducing risk by removing equipment panels.
– Redundant power supplies prevent logic failures.
– Redundant cooling fans with failure sensing avoid overheating or load loss due to fan failure.
– Shorted SCR detection prevents load loss should an outage occur.
– Downstream fault detection and isolation prevents the propagation of high-current faults to other upstream distribution systems.

1 An ABB DSTS

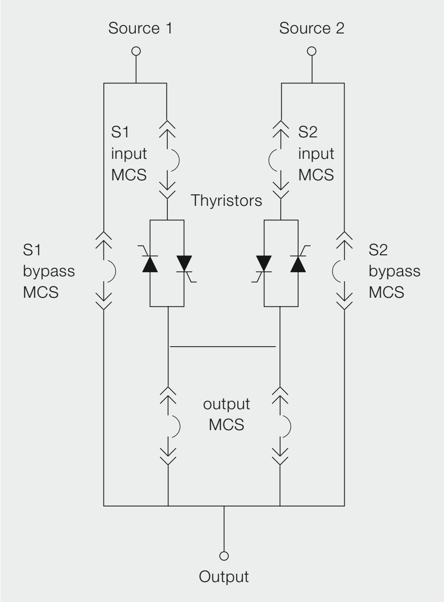
The STS is fed by two independent power sources that remain isolated from each other in all operating modes and each source's voltage, phase and waveform is continuously monitored.

In addition, since 2004 an availability of 99.9999 percent, or "six nines," has been observed for the DSTS. Further, it displays an operating efficiency of 99.60 percent at half load and 99.73 percent at full load.

Title picture
Discreetly, the ABB digital static transfer switch can instantaneously transfer power sources when the preferred source falters in any way. The end result is continuous conditioned power to a data center's critical load.

With dynamic inrush restraint enabled, peak inrush current can be limited to less than 120 percent of the peak full-load current of the transformer.

2 Single-line diagram of a typical six-MCS STS



Data center availability

In today's business environment, data centers are required to operate at extremely high reliability and efficiency levels. Data center availability, a metric known as "nines" → 3, is generally expressed as:

Availability = *MTBF*/(*MTBF*+*MTTR*)

where:

MTBF = mean time between failures = uptime

MTTR = mean time to repair = downtime.

Thus, as reliability and maintainability increase, so does availability. The need for a common standard to classify data centers' reliability and maintainability became apparent in the mid-1990s. To address this, the Uptime Institute developed a four-tiered classification benchmark that has been utilized since 1995 → 3.

Data center architecture – DSTS relevance

Some simple configurations seen in data centers can highlight the importance and flexibility of the DSTS.

Parallel redundant (N+1) design

In general, an N+1 redundant design consists of paralleled UPS modules of the same capacity and configuration connected to a common output bus → 4a. The configuration is considered N+1 redundant if a system (N) has at least one additional autonomous backup element (+1). The extra UPS module gives better availability than the N configuration and the structure makes expansion easy should facility requirements increase. The configuration does, however, have some disadvantages:

- Single point of failure with common load bus and single-corded loads
- Faults will propagate through each parallel redundant module
- Low efficiency due to light loading on the UPSs
- UPS modules must be the same rating

Distributed redundant design

A distributed redundant, or "catcher," design boasts independent input and output feeds from three or more UPS modules that are coupled with two or more STSs → 4b. Advantages compared with parallel redundant (N+1) architectures are:

- High availability at a lower cost
- Higher efficiency than parallel redundant and 2(N+1) designs
- Increased number of points of conditioned power, through UPS and DSTS
- Faults will propagate through one UPS module only
- Reduces single points of failure

The disadvantage is:

- DSTS cannot support multiple, concurrent UPS failures.

System plus system redundant with no STS (2N)

System plus system redundant (2N) topologies are the most reliable, and most expensive designs in the data center

3 The four-tier classification of data centers

Tier level	Availability (%)	Downtime (hr/yr)	Average downtime over 20 years	Common names	Requirements
Tier I	99.671	28.82	96.07	N	Nonredundant capacity components and single, nonredundant distribution path to server loads
Tier II	99.741	22.69	75.63	Parallel redundant N+1	Redundant capacity components and single, nonredundant distribution path to server loads
Tier III	99.982	1.58	5.26	Distributed redundant	Redundant capacity components and redundant distribution paths to server loads
Tier IV	99.995	0.44	1.46	System plus system multiple parallel bus 2N, 2N+1, 2N+2	Multiple isolated systems containing redundant capacity components and multiple, active distribution paths to server loads

The ABB DSTS can be applied as a two- or three-source utility switch for higher-availability applications.

world ➔ 5a. Typically, dual-corded loads are implemented. Advantages are:
– Separate power sources and paths eliminate single points of failure throughout the architecture
– Redundancy throughout the entire system
– Ability to service upstream equipment like switchgear without going into bypass mode
– Continuous conditioned power

The disadvantages are:
– High cost and large footprint
– Less efficient due to being lightly loaded
– Does not maintain power to both inputs of a dual-corded load in the event of UPS failure

System plus system redundant with STS

By definition, Tier III and Tier IV systems supply continuous power to redundant dual-corded loads. However, they do not provide redundant power availability to dual-corded loads that require quality power to not just one, but both cords continuously. One way to provide this supplementary reliability is by applying STSs ➔ 5b.

The advantages of this approach are:
– Highest level of availability
– Continuous, multiple points of conditioned power
– Separate power sources and paths eliminate single points of failure throughout the architecture (redundant throughout)
– Ability to service upstream equipment, like switchgear, without going into bypass mode
– The STS provides redundancy for dual-cord loads and protects against either source failing
– Effectively removes power quality issues upstream without causing a disturbance downstream

The disadvantages are:
– High cost and large footprint
– Low efficiency due to light loading on the UPSs

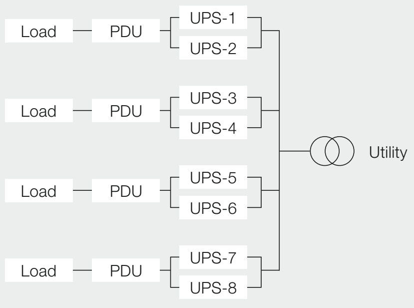
Upstream comparisons

Upstream, there will typically be a utility and backup generator, which are switched by an automatic transfer switch (ATS) ➔ 6a. Though low-cost, this solution involves longer contact transfer times, delayed power generation startup and unpredictable generator performance.

The ABB DSTS can be applied as a two- or three-source utility switch for higher-availability applications ➔ 6b. The probability of a simultaneous power outage on a fully redundant, dual-feed system is relatively low. By implementing two independent feeds from separate substations, an ABB DSTS can provide protection, switching power and speeds, and plant-wide distribution efficiencies superior to ATS. Cyberex has installed numerous large DSTSs at power entry points in data centers and industrial facilities. Though

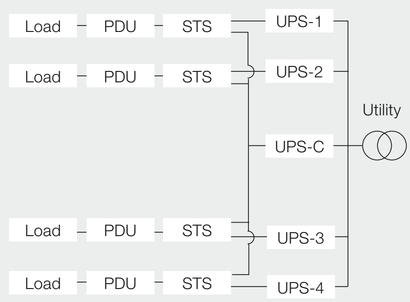
Digital signal processing hardware and patented software performs real-time analysis of the waveforms and STS logic control.

4 Parallel redundant (N+1) design with 4 loads vs. distributed redundant "catcher" design



	Parallel redundant (N+1) UPS – single-corded load
Availability (%)	99.976 (three nines)
Downtime (h/yr)	2.08
Power interruptions/20 yr	6.95
Cost ($)	1.7 million

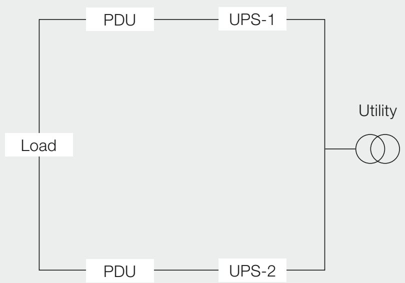
4a (N+1) design



	Distributed redundant catcher with STS – single-corded load
Availability (%)	99.976 (three nines)
Downtime (h/yr)	2.10
Power interruptions/20 yr	6.99
Cost ($)	1.28 million

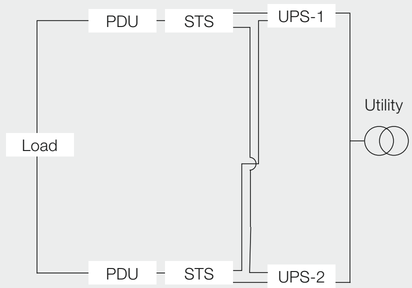
4b Distributed redundant "catcher" design

5 System plus system redundant with no STS vs. system plus system redundant with STS



	Dual UPS – dual-corded load
Availability (%)	99.987 (three nines)
Downtime (h/yr)	1.12
Power interruptions/20 yr	3.73
Cost ($)	460,000

5a System plus system redundant with no STS (2N)



	Dual UPS with STS – dual-corded load
Availability (%)	99.99999 (seven nines)
Downtime (h/yr)	0.0005
Power interruptions/20 yr	0.0017
Cost ($)	540,000

5b With STS (2N)

UPS = uninterruptible power supply / PDU = power distribution unit

more expensive than the ATS approach, and requiring two utility sources, the DSTS approach has many advantages, including:
- Highest level of upstream availability
- The DSTS removes all power anomalies propagated from the utilities and distributes continuous power to all downstream components
- Ability to service one utility source while providing continuous conditioned power from a second utility source
- Extremely high electrical distribution efficiency levels
- Flexibility to add a third source (eg, backup generator)
- Lower cost than UPS

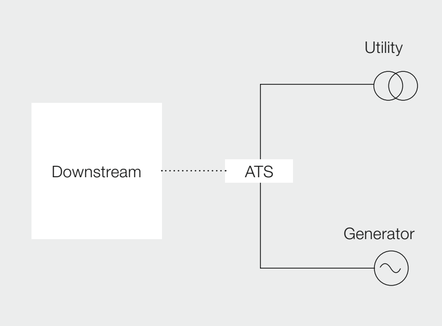
Digital STS advanced features

Apart from the advantages described above, the DSTS has further features worth noting.

Dynamic inrush restraint (DIR)

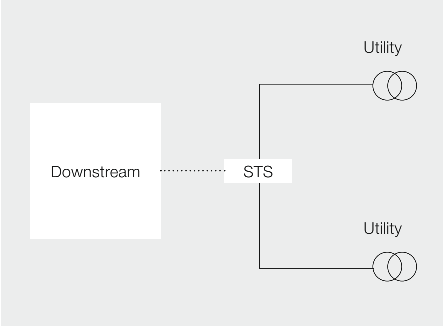
DIR limits downstream transformer inrush current when switching between two sources that are out of phase. This is done by continuously monitoring the transformer flux and precise timing of

6 Upstream comparisons



	One source, one generator - ATS upstream
Availability (%)	99.994 (four nines)
Downtime (h/yr)	0.49
Power interruptions/20 yr	1.64

6a Utility and generator with ATS



	Two sources - STS upstream
Availability (%)	99.9998 (five nines)
Downtime (h/yr)	0.013
Power interruptions/20 yr	0.044

6b Dual-utility source with STS

7 Transformer inrush current (can be up to 7,200 A for a full-load Ampere value of 600 A) when not using the DIR algorithm.

the transfer so the flux does not exceed the saturation point of the transformer's core. Energizing a transformer results in a potential peak inrush current of 5 to 12 times full-load ampacity (FLA); transferring between out-of-phase sources results in a peak inrush current of up to 20 times FLA ➔ 7.

With DIR enabled, peak inrush current can be limited to less than 1.2 times full-load current of the transformer.

PQ/sensing algorithms

Two DSPs sample the sources 10,000 times per second and utilize patented algorithms to detect source disruptions and failures in less than 2 ms, thus enabling transfers within a quarter cycle.

Smooth transfer

The DSTS source transfer algorithm transfers from an active set of SCRs to an inactive set by removing a gate signal from two parallel-connected, opposite-sense, current-carrying SCRs that, in combination, carry AC in either direction. The transfer process is simple:

1) Removal of a gating signal on the active source, due to the detection of poor PQ or a manual transfer request.
2) Current is sensed through the two active SCRs to determine the current-carrying state of each device over a specific period.
3) Once both states are determined, a gate signal is applied to the corresponding SCR in the inactive set. This enables current flow through this device while simultaneously preventing current from passing between the sources.
4) Once the SCR naturally commutates off, the gate signal is enabled on the reciprocal device to complete the transfer.

Reliability delivers availability

The ABB DSTS can effectively remove upstream power quality issues without causing a disturbance downstream. It can be a cost-effective replacement for an upstream ATS or even a facility-wide UPS system – generating improved levels of reliability while drastically reducing footprint, managing higher electrical efficiencies, and reducing overall cost.

In system plus system redundant configurations, the highest level of availability can be achieved by providing mutual, dual-bus feeds to a DSTS. This architecture provides multiple layers of redundancy that eliminate single points of failure, down to and including dual-cord load power supplies. Finally, a DSTS also provides superior fault isolation and increased protection during maintenance, ensuring continuous conditioned power is delivered to a customer's critical load.

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[2] T. A. Short, Distribution Reliability and Power Quality. 1st edition, Boca Raton, FL: CRC Press, 2006.